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1 Body Protecting Device

2

3 The present invention relates to body protecting
4 devices. In particular, but not exclusively, the
5 invention relates to the energy absorbing materials
6 used in devices having a relatively large curvature
7 such as safety helmets, elbow pads, knee pads,
8 shoulder pads and the like, and methods of forming
9 such materials.

10

11 Many body protecting devices have a large curvature,
12 κ , which is defined as the inverse of the radius of
13 curvature, ρ , for the device. The device, such as a
14 safety helmet, may require a permanently curved
15 shape. Other devices, such as pads for elbows,
16 knees and shoulders, may have to be sufficiently
17 flexible to elastically adopt such a curved shape in
18 response to movements of the body. Suitable
19 materials and forming methods must be used for these
20 devices.

21

1 Crash helmets conventionally comprise a
2 substantially spheroidal outer skin of tough
3 plastics material and an inner skin of resilient
4 material such as a hard foam. The rigid outer skin
5 transmits an impact load more evenly to the inner
6 skin which absorbs the energy imparted by the impact
7 load. The helmets are formed in a female mould, or
8 around a male mould, and the materials must undergo
9 significant curvature to form the spheroidal shape.
10 Also, the outer and inner skins must be inserted
11 separately to the mould. Otherwise, during bending,
12 the bond between the two materials would prevent the
13 necessary slippage of the outer skin (which is
14 stretched) relative to the inner skin (which is
15 compressed), or else would produce high planar
16 stresses at the internal and external surfaces.

17

18 It may be desirable to decrease the total mass of
19 the helmet. Also, the methods of forming the
20 helmets, which typically involve hand lay-up, tend
21 to be complex and expensive. It would be
22 advantageous to be able to insert the inner and
23 outer skin as a one-piece material within the mould.

24

25 Axially loaded columns of various cross sectional
26 shapes have been used for some time to improve the
27 structural crashworthiness of vehicles, roadside
28 furniture and the like. The columns of each of
29 these known systems are typically unconnected and
30 function independently. Regardless of the material
31 from which the columns are formed, a global buckling
32 failure mode (or a local failure which leads to

1 failure of the whole column) is to be avoided as
2 this does not efficiently absorb impact energy.

3

4 It is desirable that metal columns exhibit a
5 multiple local buckling and folding failure mode
6 which is effective in absorbing impact energy.

7 Plastic and composite columns have a number of
8 failure modes which are efficient for absorbing
9 impact energy but all of the modes typically involve
10 progressive crushing of one end of the column.

11

12 The performance and failure mode of plastic and
13 composite columns depends on a complex interaction
14 of a number of different parameters including the
15 material used, the geometry (shape and thickness),
16 fibre alignment in composites, the use of triggers,
17 and the loading conditions. However, a careful
18 selection of these parameters can result in a safety
19 device which outperforms the metal equivalent.

20

21 Regardless of the material used, arrays of
22 independent columns arranged parallel to the load
23 have generally been found to increase energy
24 absorbing performance and improve the stability of
25 the safety device. Columns tend to produce a
26 relatively constant level of energy absorption as
27 the column is progressively buckled or crushed.

28 Axially loaded cones have been found to produce a
29 more linearly increasing rate of energy absorption
30 which can often be more desirable in crash
31 situations. However, as the columns are
32 independent, a localised load can cause an

1 undesirable global failure of columns which have an
2 axis which is offset from the axis of the applied
3 load. Also, as the columns are independent, the
4 columns are formed to be relatively thick to avoid
5 instability during loading.

6
7 Sandwich panels, consisting of two tough outer skins
8 separated by a core material having a lower
9 stiffness, have been used in many applications such
10 as building components and structural panels for
11 road vehicles and aircraft. A popular core consists
12 of a honeycomb structure, that is an array of cells,
13 each cell having a hexagonal cross-section.
14 However, these cells, or cells of other cross-
15 sections cannot be regarded as connected columns
16 since each side wall is shared with the neighbouring
17 cells. If one cell experiences local failure or
18 instability then this will affect the neighbouring
19 cells.

20
21 The axis of each longitudinal member is normal to
22 the plane of the inner and outer skins and each end
23 of each longitudinal member is typically bonded to
24 the respective skin. Therefore, the honeycomb
25 structure represents an array of cells arranged
26 parallel to a load which impacts the plane of one of
27 the outer skins.

28
29 WO 94/00031 discloses a safety helmet which includes
30 a honeycomb sandwich structure. Generally, a hand
31 lay-up method is used. EP 0881064 discloses a
32 protective element which also has a honeycomb

1 sandwich structure. The document states that the
2 element may be incorporated within a wide range of
3 protective clothing which includes helmets.

4
5 US 3877076 discloses a helmet having an array of
6 tubes. Each of the tubes is spaced apart and
7 independent from the others.

8
9 US 4534068 also discloses an array of tubes which
10 are spaced apart. A local crippling failure is
11 described.

12
13 Honeycomb structures are suitable for applications
14 involving flat panels or structures with only a
15 relatively small curvature. However, problems arise
16 when the material is used in items having a large
17 curvature.

18
19 Each hexagonal cell of the honeycomb structure has a
20 rotation symmetry angle of $n.60^\circ$. The cell
21 therefore does not have rotation symmetry about an
22 angle of 90° . The cell is therefore not
23 orthotropic, that is it has a different response to
24 a load applied at a first angle than to a load
25 applied at a second angle which is applied at 90°
26 from the first angle. When forming a helmet, the
27 material is bent around a mould about two orthogonal
28 axis to form the spheroidal shape. Therefore, a
29 hexagonal structure can create difficulties when
30 trying to achieve the curvature desired.

31

1 Furthermore, a hexagonal structure is by nature
2 anticlastic, in that a positive curvature about an
3 axis results in a negative curvature about an
4 orthogonal axis (the shape of a saddle illustrates
5 this phenomenon). This again leads to difficulties
6 in the forming process.

7

8 Furthermore, there are disadvantages in using a
9 honeycomb structure for devices such as pads which
10 must elastically deform to a large curvature. These
11 disadvantages include the relatively rigid nature of
12 the structure. A hexagonal element can be
13 considered to be six flat plates, each of which are
14 rigidly fixed at each longitudinal edge. It is
15 known theoretically and empirically that such
16 elements, and structures produced from these
17 elements are relatively inflexible. A pad produced
18 from such a material can tend to feel stiff and less
19 comfortable. It is desirable that comfort be
20 improved without any sacrifice in the energy
21 absorbing capability of the device.

22

23 According to a first aspect of the present invention
24 there is provided a body protecting device for
25 wearing by a user comprising:

26 an array of energy absorbing cells, wherein
27 each cell comprises a tube, and wherein
28 substantially each tube has a side wall which is
29 near or adjacent to the side wall of at least
30 another tube, and wherein substantially each tube is
31 configured such that the orientation of the tube is

1 substantially maintained when a load is applied
2 parallel to the axis of the tube.

3

4 The term "tube" is used to denote a hollow structure
5 having any regular or irregular geometry.

6 Preferably the tube has a cylindrical or conical
7 structure, most preferably a circular cylindrical or
8 circular conical structure. The circular tubular
9 array results in a material which is substantially
10 isotropic and substantially non-anticlastic.

11

12 Preferably the body protecting device comprises a
13 safety helmet. Alternatively, the body protecting
14 device comprises a safety pad.

15

16 Preferably substantially each tube has a side wall
17 which abuts the side wall of at least another tube.
18 Preferably substantially each tube has a side wall
19 which is connected to the side wall of at least
20 another tube.

21

22 Preferably substantially each tube has a side wall
23 which is connected to the side wall of at least
24 another tube by an adhesive. Preferably
25 substantially each tube has a side wall which is
26 connected to the side wall of at least another tube
27 substantially along the length of the tube.

28

29 Alternatively, substantially each tube has a side
30 wall which is welded or fused to the side wall of at
31 least another tube.

32

1 One or more tubes may be formed from an inner core
2 comprising a first material and an outer core
3 comprising a second material. Preferably each of
4 the first and second material is a polymer.
5 Preferably the second material has a lower melting
6 temperature than the first material. Preferably the
7 first material comprises polyetherimide. Preferably
8 the second material comprises a blend of
9 polyetherimide and polyethylene terephthalate.
10
11 Preferably substantially each tube is near or
12 adjacent to at least three other tubes. Preferably
13 substantially each tube is near or adjacent to six
14 other tubes.
15
16 Preferably each tube has a diameter of between 2 and
17 8 mm. Preferably each tube has a diameter of about
18 6 mm.
19
20 Preferably the thickness of the side wall of each
21 tube is less than 0.5 mm. Preferably the thickness
22 of the side wall of each tube is between 0.1 and 0.3
23 mm.
24
25 Preferably the length of each tube is less than 50
26 mm. Preferably the length of each tube is between
27 30 and 40 mm.
28
29 Preferably the array of energy absorbing cells is
30 provided as an integral material. Preferably the
31 integral material has, or can deform to, a large
32 curvature.

1
2 Preferably the integral material comprises
3 polycarbonate, polypropylene, polyetherimide,
4 polyethersulphone or polyphenylsulphone. Preferably
5 the material comprises Tubus Honeycombs™.

6
7 According to a second aspect of the present
8 invention there is provided a liner for a body
9 protecting device for wearing by a user, the liner
10 comprising:

11 a first material having an array of energy
12 absorbing cells, wherein each cell comprises a tube,
13 and wherein substantially each tube has a side wall
14 which is near or adjacent to the side wall of at
15 least another tube, and wherein substantially each
16 tube is configured such that the orientation of the
17 tube is substantially maintained when a load is
18 applied parallel to the axis of the tube.

19
20 Preferably the body protecting device comprises a
21 safety helmet. Alternatively, the body protecting
22 device comprises a safety pad.

23
24 According to a third aspect of the present
25 invention, there is provided a body protecting
26 device comprising:

27 a first material bonded to a second material
28 using an adhesive, wherein the adhesive has a melt
29 temperature which is lower than the melt temperature
30 of the first and second material.

31

1 Preferably the body protecting device comprises a
2 safety helmet. Alternatively, the body protecting
3 device comprises a safety pad.

4

5 Preferably the first and second materials are in a
6 softened state at the melt temperature of the
7 adhesive. This allows thermoforming of the helmet
8 at the melt temperature of the adhesive, as the
9 melted bond allows relative movement between the
10 first and second materials.

11

12 Preferably the first material is one of a
13 polycarbonate, polypropylene, polyetherimide,
14 polyethersulphone or polyphenylsulphone material.

15

16 Preferably the second material is a plastics
17 material, such as polyetherimide. Preferably the
18 second material is a fibre reinforced plastics
19 material. Preferably the fibres are made from glass
20 or carbon.

21

22 Preferably the adhesive is a thermoplastic.
23 Preferably the adhesive is a polyester based
24 material.

25

26 Preferably the melt temperature of the adhesive is
27 less than 180°C. Preferably the melt temperature of
28 the adhesive is between 120°C and 140°C.

29

30 Preferably the body protecting device is heated
31 during forming to between 155°C and 160°C.

32

1 Preferably the body protecting device further
2 comprises a third material and the first material
3 interposes the second and third materials.
4 Preferably the first material is bonded to the third
5 material using the adhesive.

6
7 Preferably the first material has an array of energy
8 absorbing cells, each cell comprising a tube.

9
10 According to a fourth aspect of the present
11 invention there is provided a method of forming a
12 body protecting device comprising:
13 bonding a first material to a second material
14 using an adhesive, wherein the adhesive has a melt
15 temperature which is lower than the melt temperature
16 of the first and second material.

17
18 Preferably the body protecting device comprises a
19 safety helmet. Alternatively, the body protecting
20 device comprises a safety pad.

21
22 Preferably the method includes selecting first and
23 second materials which are in a softened state at
24 the melt temperature of the first material.

25
26 Preferably the method includes heating the body
27 protecting device during forming to between 155°C
28 and 160°C.

29
30 Preferably the method includes bonding the first
31 material to a third material using the adhesive.

32

1 Preferably the first material has an array of energy
2 absorbing cells, each cell comprising a tube.

3

4 An embodiment of the present invention will now be
5 described, by way of example only, with reference to
6 the accompanying drawings, in which:

7

8 Fig. 1 is a perspective view of a safety helmet in
9 accordance with the present invention;

10

11 Fig. 2 is a side view of the sandwich panel used to
12 form the helmet of Fig. 1;

13

14 Fig. 3 is a side view of the sandwich panel of Fig.
15 2 in a curved state;

16

17 Fig. 4 is a plan view of a known arrangement of
18 cells used for the core of a sandwich panel.

19

20 Fig. 5 is a plan view of a tubular array of cells
21 used in the sandwich panel of Fig. 2;

22

23 Fig. 6 is a sectional side view of the tubular array
24 of Fig. 5 in a curved state;

25

26 Figs. 7a, 7b and 7c are exaggerated plan views of
27 positions of the tubular array of Fig. 6 which are
28 compressed, neutral and extended respectively;

29

30 Fig. 8 is a side view of the heating process used
31 for the sandwich panel of Fig. 2;

32

1 Fig. 9 is a cross sectional side view of a mould
2 used in conjunction with the sandwich panel of Fig.
3 2; and

4
5 Fig. 10 is the sandwich panel of Fig. 2 in a moulded
6 state.

7
8 Referring to Figs. 1 to 3, there is shown a body
9 protecting device in the form of a safety helmet 10.
10 The helmet 10 is formed using a panel 12 which
11 comprises a first material or core 20 which is
12 sandwiched by a second material or outer skin 30 and
13 a third material or inner skin 50. Each of the
14 outer 30 and inner 50 skins are bonded to the core
15 using an adhesive 40.

16
17 Fig. 3 shows the sandwich panel 12 in a curved
18 state. In such a state, the material varies
19 linearly from a state of zero stress (in respect of
20 the major planes of the panel 12) at the neutral
21 axis 14 to a state of maximum tensile stress at the
22 exterior face of the outer skin 30 and a state of
23 maximum compressive stress at the interior surface
24 of the inner skin 50. These tensile and compressive
25 stresses cause tensile and compressive strains
26 respectively. Therefore, there is slippage between
27 the outer skin 30 and the core 20 and the inner skin
28 50 and the core 20 unless this slippage is prevented
29 by the adhesive 40.

30
31 A known core structure is a honeycomb or hexagonal
32 arrangement which is shown in Fig. 4. Each

1 hexagonal cell 60 has a rotation symmetry angle 62,
2 64 of 60° , 120° and so on, or in other words of
3 $n \cdot 60^\circ$, where n is an integer. Therefore, the cell
4 does not have a rotation symmetry angle of 90° and so
5 the overall material is not orthotropic. Also, the
6 material will be anticlastic.

7
8 Furthermore, the honeycomb cells 60 cannot be
9 regarded as connected columns since each of the six
10 side walls of each cell 60 is shared with the
11 neighbouring cells.

12
13 Fig. 5 shows an array of cells for the core material
14 20 according to the invention. Each cell comprises
15 a tube 22. The tubes 22 are arranged in a close
16 packed array such that the gap between adjacent
17 tubes is minimised. Each tube has a diameter of 6
18 mm, a thickness of between 0.1 and 0.3 mm, and a
19 length of around 35 mm. This results in a
20 slenderness ratio (the ratio of the length to the
21 diameter) of between 100 and 350, and an aspect
22 ratio (the ratio of the diameter to the thickness) of
23 between 20 and 60. It is to be appreciated that
24 these values are one or two orders of magnitude
25 greater than prior art arrangements.

26
27 The use of these geometric values, particularly the
28 low thickness used, results in the desirable failure
29 mode of progressive buckling being achieved, even
30 when a polymer material is used for the tubes.
31 Instability, which could lead to a global buckling
32 failure mode, is avoided since the tubes are

1 connected to, and supported by, adjacent tubes.
2 Being connected to six other tubes which are
3 circumferentially spaced around the tube provides
4 such support in any direction normal to the axis of
5 the tube. Therefore, the orientation of each tube
6 (typically parallel to the axis of an applied load)
7 is substantially maintained during progressive local
8 buckling caused by the applied load.

9
10 The tubes may be bonded together using an adhesive.
11 Another suitable method is to form the tubes from an
12 inner core of a first material and an outer core of
13 a second material, the cores being co-extruded. The
14 second material can be selected to have a lower
15 melting temperature than the first material.
16 Typically, a difference of between 15 and 20 degrees
17 Celsius can be used. During forming, the tubes can
18 be heated to a temperature between the melting
19 temperature of the first and second material. This
20 causes the side walls of the tubes to become welded
21 or fused together. This method allows easier
22 forming of shapes and gives better consistency
23 during forming.

24
25 It is to be appreciated that the tubes need not be
26 connected to provide support to each other, or even
27 be abutting, as long as the tubes are in close
28 proximity such that they come into contact following
29 a small amount of deformation.

30
31 It is known empirically that an apparatus according
32 to the invention can provide an efficiency of energy

1 absorption of greater than 80% which is a
2 significantly improvement on prior art devices.
3
4 Since each tube 22 has an infinite rotation symmetry
5 angle, the overall tubular array results in a
6 material which is substantially isotropic and non-
7 anticlastic. Nevertheless, the tubes could have
8 cross sections other than circular and still provide
9 a superior energy absorption provided that each tube
10 has a side wall which is near to the side wall of
11 other tubes.
12
13 Fig. 6 shows the tubular array in a curved state.
14 As described above, the planar stress and strain at
15 the neutral axis 14 is zero and so each tube 22
16 retains its circular shape as shown in Fig. 7a. At
17 the inner surface 24, the tubes 22 will be
18 compressed in the direction of the curvature, and
19 the profile of the tubes at this position is shown
20 in exaggerated form in Fig. 7b. At the outer
21 surface 26, the tubes will be elongated in the
22 direction of curvature and the profile of the tubes
23 at this position is shown in Fig. 7c.
24
25 It should be noted that, despite compression and
26 extension of the tubes 22, the profile of the tubes
27 22 when averaged through the thickness of the
28 material 20 will be as found at the neutral axis 14.
29 Also, if there is curvature about an orthogonal
30 axis, this will tend to cause compression and
31 extension in an orthogonal direction, tending to
32 cause the profile of the tubes 22 at any point

1 through the thickness to be as found at the neutral
2 axis 14, although the diameter of the tubes 22 will
3 be reduced at the inner surface 24 and enlarged at
4 the outer surface 26. The tube will in effect be a
5 cone which may even improve the energy absorbing
6 capability of the structure.

7
8 The helmet is formed using a suitable thermoforming
9 process. As shown in Fig. 8, the sandwich panel 12
10 is heated using heaters 70 to a temperature of
11 between 155°C to 160°C, which is above the melt
12 temperature of the adhesive 40.

13
14 The sandwich panel 12 is then transferred to a mould
15 as shown in Fig. 9. The male portion 72 of the
16 mould typically has a rubber contacting face and the
17 female portion 74 is typically constructed from
18 aluminium. The mould is at ambient temperature and
19 the transfer of the panel 12 should be effected
20 quickly, preferably in less than 6 seconds to
21 minimise cooling of the panel 12. The male part 72
22 is then driven towards the female part 74 so that
23 the panel 12 assumes the shape of the mould.

24
25 Since the panel 12 has been heated to above the melt
26 temperature of the adhesive, slippage can take place
27 between the outer skin 30 and the core 20, and
28 between the inner skin 50 and the core 20. Cooling
29 of the panel 12 to a temperature below 50°C ensures
30 that the panel has assumed the curved profile and
31 the adhesive once again bonds each of the skins 30,
32 50 to the core 20. The two parts of the mould can

1 now be separated. The curved panel 12 is shown in
2 Fig. 10.
3
4 Various modifications and improvements can be made
5 without departing from the scope of the present
6 invention. For instance, the tubes of the array may
7 be conical and have a cone angle of any angle.
8
9